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COMMERCIAL FERTILIZERS AND SOIL FERTILITY IN CALIFORNIA

P. L. HIBBARD

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P. L. HIBBARD[1]

For proper development and healthy growth, plants need water, air, light, and a favorable temperature. They also need space for roots to form a physical support and from which the plant may derive its mineral nutrients, as well as suitable conditions of soil as to tilth, aeration, and drainage. Another, and most essential requirement, is the need for the substances out of which plant material is formed. These substances may be called plant nutrients. Of these nutrient substances, plants require large amounts of water, carbon dioxide, oxygen, calcium, magnesium, sulfur, nitrogen, phosporus, and potassium.

Very small amounts of manganese, iron, silicon, boron, zinc, and probably of sodium, chlorine, aluminum, copper, nickel, cobalt, and some other elements seem to be essential to healthy normal growth of many if not all kinds of plants. Adequate supplies of all of these elements are usually available to plants in ordinary soils. Excessive amounts of some of them are generally toxic to plants.

The various substances which plants use, in particular nitrogen, phosphorus, and potassium, are frequently spoken of as plant foods. More correctly it may be said that these substances are the raw materials from which plants synthesize their foods. The plant takes the substances coming from soil, air, and water and combines them in the leaves by aid of light and heat to make sugar, starch, nitrogenous compounds, etc., which are transported to the various parts of the plant, where they are used to produce wood, bark, leaves, flowers, seeds, etc., thus producing the whole plant which we see as perhaps a grass plant, a potato plant, or an apple tree.

Since most of the mineral substances needed by plants are usually found in sufficient amounts in the soil, only three are commonly considered as fertilizers. These are nitrogen, phosphorus, and potassium. Heavy cropping often exhausts the available supply of these elements in the soil so that it becomes necessary to add one or more of them in order to continue to produce good crops. This brings us to the subject of fertilizers.

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[1] Associate Chemist in the Experiment Station.

A commercial fertilizer, for the purpose of this discussion, is a material which supplies one or more of these three elements, nitrogen, phosphorus, and potassium, in considerable amounts and in such condition that it is suitable for absorption by plants. The material should at once easily dissolve in the soil moisture, or soon become soluble by the process of decaying. Many substances, even the soil itself, contain small amounts of these three elements, but not enough to be considered as fertilizers. Other substances contain large amounts of these elements, but not in a condition for plant nutrition. Leather contains much nitrogen but not in a form suitable for nourishing plants. There is much potassium in the mineral feldspar, but this mineral is practically useless as a fertilizer, although considerable amounts of it are present in many soils.

Organic matter, lime, and sulfur are needed in a good soil, but these are not usually spoken of as commercial fertilizers.

FUNCTIONS OF THE VARIOUS ELEMENTS IN PLANT NUTRITION[2]

Plant physiologists for many years have endeavored to determine the precise function of the various elements needed by plants. Something is now known, though it is still impossible to answer these questions satisfactorily. For the present purpose it will suffice to consider only the three elements commonly used as fertilizers, namely, nitrogen, phosphorus, and potassium.

The chemist's symbols, N, P, and K are commonly used to designate the elements nitrogen, phosphorus, and potassium, respectively, in technical literature and that of fertilizers. In the common inexact language of everyday discussion, nitrogen is sometimes confused with, or supposed to be the same as ammonia, in respect to its function as a fertilizer. Phosphorus, phosphoric acid, and phosphate, are quite different substances, though these names are often used as if synonomous in common speech. Also potash and potassium are frequently used as if these words meant the same thing, though these substances are very unlike.

In the present discussion, common usage is followed, so that potash or potassium indicate the same thing in a fertilizer; also phosphoric acid, phosphate, or phosphorus may be used somewhat interchangeably in speaking of phosphorus in fertilizers or plant nutrients.

[2] For a more extended discussion of this subject see: Hoagland, D. R. Fertilizer problems and analysis of soils in California. California Agr. Exp. Sta. Cir. 317:1–16. 1930.

The following statements in respect to the functions of the elements nitrogen, phosphorus, and potassium in plant nutrition, are not to be considered as statements of facts, so far as California soils are concerned, but only as a summary of common opinion on the subject. Scientists who have studied the matter most, are still very uncertain about many of the points mentioned. It is not yet possible to make reliable statements as definite as the farmer, or the fertilizer manufacturer would like to have.

When any one of the elements, nitrogen, phosphorus, or potassium, is so lacking that growth of plants is much restricted, it is spoken of as the limiting factor if there is an adequate supply of the other two. In case the supply of either of the two is low, one of them may become the limiting factor in plant growth, after the supply of the previously deficient element is made adequate.

The important point is to produce a favorable condition in the soil for the growth of plants by adding that element in which the soil is deficient. In the majority of cases, California soils are most likely to be deficient in nitrogen.

Nitrogen (N) is the chief promoter of vegetative growth. Provided other elements are in adequate supply, nitrogen is likely to cause rapid luxuriant growth of dark green foliage. It tends to produce soft, succulent plant tissue such as is desired in lettuce or celery, but not in the straw of grain. Too much nitrogen may make the straw long, soft, and weak, so that the grain falls down in a heavy wind or rain, or, as the farmers say, it 'lodges' badly. However, such effects of nitrogen are very greatly modified by available soil moisture, temperature, sunshine, and time of application of the fertilizer.

Plants lacking sufficient nitrogen are likely to be small, weak, and yellowish in color, especially in cold, wet spring weather. Grass lacking sufficient nitrogen grows slowly. These various effects of nitrogen may sometimes be modified by the supply of phosporus and potassium, so that for best results an adequate amount of these two as well as nitrogen should be present in the soil.

Phosphorus (P) is found in both the vegetative and the reproductive organs of plants. It is usually present in seeds in a larger proportion than in other parts of the plant. Plenty of easily available phosphorus in the soil often favors early development of an extensive root system of the plant. A large root system is likely to be very advantageous to plants, especially on a poor soil. Also, abundance of available phosphorus is supposed to make the plant healthier and more vigorous so that it is better able to resist disease or insect pests.

Early maturity of many kinds of plants may be promoted by plenty of phosphorus. An excessive supply of phosphorus generally does not injure or make itself evident in abnormal behavior of the plant. This is in great contrast with the effects of excessive nitrogen supply.

Potassium (K) is absolutely essential to the growth of plants, though it is not yet possible to tell how it operates. Plants suffering from lack of available potassium may be the first to fail under adverse climatic conditions or attack of disease. The somewhat common opinion that addition of potassium to the soil increases the total yield per acre of such crops as potatoes or sugar beets, has not been well supported in California experience, except on peat soils and on some sandy soils. Also, contrary to common belief, there is little evidence that fertilization with potassium makes fruits sweeter. An excess of any potassium salt in the soil (though this is not likely to happen) is injurious to plants, as is an excess of other easily soluble salts, which are commonly spoken of as alkali.

Since the purpose of this circular is to give information about commercial fertilizers chiefly, the function of other elements needed by plants will not be considered here. Sometimes other substances than nitrogen, phosphorus, and potassium, become limiting factors. In California bad physical condition of the soil, lack of organic matter, and improper moisture conditions may frequently be the limiting factors.

THE NITROGEN CYCLE

Plants require large amounts of nitrogen. The air is four-fifths nitrogen, but most plants are unable by means of the leaves or roots to assimiliate air nitrogen, that is, free or uncombined nitrogen, at least not in important amounts. Therefore it is absorbed from the soil through the roots. This nitrogen is always taken up in a state of chemical combination, usually as nitrate, sometimes as an ammonium salt. The plant utilizes the nitrogen from these compounds and recombines it with carbon, hydrogen, oxygen, phosphorus, and sulfur to form a great variety of vegetable substances. When plant residues go back to the soil and decay, these various nitrogen compounds in the plant material are changed by soil bacteria back to their original form, ammonium salts and nitrates, which are then ready for use by other plants. This series of changes in the form of combination of the nitrogent is known as the nitrogen cycle. The inorganic nitrogen in the states of combination known as nitrate and

ammonia is taken up from the soil by plants and made into plant material. When the plant material decays, most of the nitrogen in it is again converted back into its inorganic form, nitrate or ammonia, by certain kinds of bacteria. But at the same time other species of bacteria in the soil may change some of the nitrogen in the plant material back into the form of free nitrogen in which it originally existed in the atmsophere. This free nitrogen is of no use to most species of plants until it has again been changed into the form of nitrate or ammonia and dissolved in the soil moisture. This change may be brought about in two ways, by chemical action in a factory, or by action of some species of bacteria, or perhaps other simple plants in the soil. The nitrogen-fixing bacteria exist chiefly on the roots of plants of the legume family. Under some conditions other nitrogen-fixing organisms, not requiring an association with legumes, may be of considerable importance.

Most members of the legume family of plants are able to supply themselves with sufficient nitrogen taken from the air by the aid of these nitrogen-fixing bacteria. In this connection, it should be stated that when these legumes find plenty of available nitrogen in the soil, they usually supply their needs from that source instead of fixing free nitrogen from the air. In consequence of this fact, it is usually not possible to cause accumulation of large amounts of fixed nitrogen in the soil at any one time by the growing of legumes.

Nitrate nitrogen is the most important form of nitrogen for absorption by plants, though ammonium salts are sometimes used. When other forms are given as fertilizers, they are usually converted to nitrate by the soil bacteria before they are utilized by the crop plants. Nitrate nitrogen is easily assimilated by most plants without first having to be converted into some other form. For this reason, it is usually the most useful form in which nitrogen may be used as a fertilizer. Since nitrates are easily soluble in water, they are liable to be washed out of the soil by heavy rains, or by irrigation if too much water is used. Therefore, it is sometimes better to add part of the nitrogen in the form of some organic fertilizer. This will be gradually converted to nitrate as the crop needs it and it is not so likely to be lost in the drainage. Because of the present high cost of organic nitrogen, it may be cheaper to make two or three applications of the less expensive materials which supply inorganic nitrogen.

SOURCES OF NITROGEN, PHOSPHORUS, AND POTASSIUM

Vast amounts of nitrogen combined as sodium nitrate are found in Chile and some are found in other parts of the world. Small amounts of nitrate are found in arid parts of the United States. Much nitrogen originally contained in plants is now present in coal and coal shales. When coal is made into coke much of its nitrogen may be recovered as ammonium sulfate and this becomes available as a fertilizer. At the present time large amounts of combined so-called 'synthetic nitrogen' are being made from the air. The amount thus produced is increasing rapidly. The synthetic nitrogen is placed on the market as nitrate, ammonium salts, urea, or in other combinations, which are essentially the same in character and value as the common so-called 'natural fertilizer materials'. Experience with some of the recently introduced combinations is not sufficient to warrant any positive statements as to their value.

Immense amounts of phosphorus are found in phosphate rock in various parts of the world. The United States has more than is known to exist in any other country. When fertilizers were first beginning to be used, bones were the main source of phosphate and even yet much bone-meal is used as a fertilizer. A considerable amount of the phosphorus used as fertilizer is a by-product of steel making, especially in Europe. This substance, known as basic slag or Thomas phosphate, is a very good phosphate fertilizer. It is not easily obtainable in western United States at the present time.

Potassium used as a fertilizer, in the past, came mostly from German potash mines. Similar deposits are now beginning to be worked in other parts of the world. There seem to be large amounts of such deposits available in Texas, though they are not yet developed. A superior quality of potassium chloride is now being produced in large amounts from Searles Lake, in southern California. Wood ashes, waste molasses, and sea weed, blast-furnace dust, and cement-mill dust are minor sources of fertilizer potash not ordinarily much used but capable of supplying considerable amounts in cases of emergency.

IMPORTANCE OF ORGANIC MATTER IN THE SOIL

Organic matter, as found in the soil, consists chiefly of the more or less decomposed remains of plants, such as straw, leaves and roots of previous crops and of manure. Organic matter aids in holding moisture in the soil, makes clayey soil easier to till, increases the rate of penetration of water, and helps to hold sandy soils together. Thus by improving the physical condition of the soil it helps to make fertilizers more effective.

In a good fertile soil there live a great variety of microscopic plants and animals, mostly bacteria and fungi. Without them a soil is dead and inert like sand or ashes. These small organisms live on organic matter and decompose it so that the plant food elements which it contains are again made available to furnish nutriment to growing crops.

Until recent years, farm manures supplied the greater part of the organic matter used on most farms. The supply is now very inadequate, so that it may become necessary to supply other forms. Well-rotted manure is an excellent source of plant nutrients in most cases. Most manures are extremely variable in composition, usually deficient in available phosphorus and potassium, though some of the dried and pulverized manures now on the market supply much potassium.

The compost heap which is a pile of any waste material such as straw, leaves, lawn clippings, weeds, etc., mixed with some soil, may be made to spply small amounts of organic matter similar to manure in general character and effects. If kept moist, turned over, and mixed occasionally, the material gradually rots down to a condition very suitable to use on gardens or lawns.

A process for making manure from straw and other waste vegetable materials was worked out at the Rothamstead Experimental Station in England, a few years ago. The treatment is somewhat as follows: To 1 ton of straw is added a mixture of about 75 pounds ammonium sulfate, 50 pounds superphosphate, and 100 pounds of powdered limestone. This is mixed with the straw. The whole mass is kept moist by frequent watering, and it is occasionally turned over. After about three months, the straw becomes well rotted. The material thus produced is quite similar in appearance, composition, and effects to the ordinary farm manure. Experience with it in the

United States is still too meager to warrant any very positive statements as to its value as a source of organic matter for the soil. The process is patented under the name of "Adco Process."

Some of the experiment stations have worked with this process and published information in regard to it. Among them are the New York, Iowa, and Missouri stations. Reports from these stations indicate that the process is feasible, although it is not certain that it will pay the farmers to use this method.

Some recent research in Germany and in Washington seems to indicate that there is little advantage so far as fertilizing value is concerned, from the use of the artificial manure except from the nitrogen which is added during the process. If this is true, it would be simpler and cheaper to scatter the strawy material on the field without composting, then add the nitrogen fertilizer to the soil directly instead of to the compost. However, this method would lack the advantage of having a well-rotted material which could be easily worked into the soil without interfering with surface cultivation.

At the present time it is perhaps easier and cheaper to obtain organic matter by means of a covercrop or green manure crop than in any other way. For this purpose legumes are usually best as they can obtain nitrogen from the air. Legumes are plants having irregular winged blossoms, such as alfalfa, clover, beans, peas, melilotus, etc. Other crops such as rye, mustard, or rape furnish a large amount of organic matter but do not fix nitrogen taken from the air. Almost any easily rotted green crop, such as many a common weed, is good for green manure if it contains enough nitrogen to satisfy the needs of the bacteria which cause rapid decay. If the nitrogen content is not adequate this may be supplemented by addition of inorganic sources of nitrogen such as nitrate or ammonium salts.

What is the best legume or other plant to grow for green manuring, depends on circumstances. Usually it is that one which will give the greatest growth of organic matter at the time when it must be plowed in. The farm advisor or experienced farmer usually knows what is best in his locality. Sometimes the soil is so poor or exhausted by cropping that it will not grow even a good covercrop. It may pay to use a little nitrate to start a covercrop, even a legume crop. Worn out or poor soils may require addition of phosphate or potassium or both in order to produce a satisfactory covercrop. When there is very little organic matter in the soil, it may even be necessary to add manure to get a satisfactory covercrop started.

During the decomposition of organic matter in the soil small amounts of several acids are formed. It seems probable that these acids serve a useful purpose in increasing fertility by acting on the raw inert mineral matter of the soil, some of which is thus converted into a condition suitable for plant nutrition. In this way organic matter acts as a fertilizer.

It is possible for many plants to grow in a soil such as sand, which contains no organic matter, provided suitable fertilizers are adequately supplied. In this way the soil gains in organic matter by accumulation of roots, dead leaves, etc., which thus help to make more plant food available by their decay, as above stated. By this means mineral fertilizers can help to build up a soil by increasing organic matter so that the fertility of the soil will be to some extent self-perpetuating.

One difficulty with the use of any kind of organic matter in dry countries is that when plowed under it tends to insulate the top soil from the subsoil, so that the top dries out and young plants die. The farmer says they are 'burned out.' To avoid this difficulty, the organic material should be used in moderate amounts at any one time and be plowed or disked in when green, and while the ground is moist so that it will decay promptly and not form a dry layer between top soil and subsoil. Another trouble in the use of organic matter is that during the early stages of decay the bacteria which decompose it may use up all the nitrate in the soil so that none is available to the higher plants which the farmer wishes to grow. Addition of a nitrate fertilizer at this time supplies the necessary nitrogen to the growing crop until the organic matter which has been plowed in is sufficiently decayed to begin to supply nitrate. Legume green manures are preferable because they contain more nitrogen and the difficulty just mentioned is less likely to be troublesome with them.

The following named legumes are recommended[3] as green manure crops for California:

Winter-growing

Hubam clover
Bitter clover
Bur clover
Garbanzos (*Cicer*)
Small-seeded horse beans
Tangier pea
Fenugreek
Hairy vetch
Purple vetch
Woolly-podded vetch
Monanthos lentil
Lupines
Canadian field peas

[3] The list is taken, for the most part, from: Kennedy, P. B. Leguminous plants as organic fertilizers in California agriculture. California Agr. Exp. Sta. Cir. 255:7. 1922.

Summer-growing

Cowpeas
Velvet beans
Soybeans
Mung beans
Tepary beans
Berseem clover
Peanuts
Alfalfa
Sesbania
Moth bean

Sandy soil

Bitter clover
Hairy vetch
Bur clover
Lupines
Peanuts
Cowpeas
Soybeans
Canadian field peas

Alkali tolerant

Berseem clover
Sweet clover
Hubam clover
Alfalfa
Hairy vetch
Horse beans

Heavy soil

Peas
Tangier pea
Horse beans
Mung beans
Sesbania
Fenugreek

Nonlegumes such as rye, oats, mustard, and buckwheat, and also many common succulent weeds such as malva and pigweed, are sometimes used for green manuring.

SUFFICIENT MOISTURE NECESSARY TO EFFECTIVE USE OF FERTILIZERS

Most writers on the subject of fertilizers have given little attention to the matter of adequate moisture in the soil. In California or other regions where natural rainfall is not sufficient for the growth of good crops, lack of moisture in the soil is, perhaps more than any other one thing, the limiting factor in successful agriculture.

Fertilizers can be of little use unless there is sufficient water in the soil to permit good growth of plants. All substances absorbed from the soil by plants must be dissolved in the soil moisture before they can be taken up by the plants. Consequently the farmer should not expect to gain much from application of any kind or amount of fertilizer unless he has means to maintain an adequate supply of moisture in the soil. In California it appears that where the natural supply of water is not sufficient to carry the crop to maturity it does not pay to use fertilizers unless water for irrigation is available when needed. It is probably better to have plenty of water and save on the fertilizer. A plentiful supply of plant nutrients in the early portion of the life of the plant may induce such a rank growth that the usual supply of water is inadequate to carry the crop to maturity and so the crop fails.

NEED FOR LIME AND SULFUR IN THE SOIL

Both lime (calcium) and sulfur are necessary to produce healthy, normal plants. A large proportion of California soils contain sufficient amounts of these substances to supply the needs of any ordinary crop. Yet there seem to be some places where soils are improved by the addition of one or both of them. There seems to be no practical method for finding out whether lime or sulfur will be advantageous except to try them. In most places the farm advisor will be able to tell the farmer of the results of experiments with these amendments in his locality. This has no reference to the importance of lime and sulfur in reclamation of alkali land. Usually commercial fertilizers supplying nitrogen, phosphorus, and potassium will give better results where there is no lack of lime or sulfur.

Ordinary gypsum, which is lime sulfate, supplies both lime and sulfur more cheaply than any other source. Common superphosphate, on the other hand, is about half gypsum, and when much of it is applied to the soil there is likely to be little need for more lime or sulfur so far as plant nutrition is concerned. The farmer who is urged to buy one or the other, or both of these amendments, will do well to try them on a small plot first to see if they do any good, before going to the expense of treating his whole place with them.

SOIL ANALYSIS NOT A RELIABLE GUIDE TO DETERMINE NEED FOR FERTILIZERS

To determine with a satisfactory degree of certainty the relative fertility of different soils has long been the objective of soil science, yet the results are often very unsatisfactory. Thus it is quite commonly believed that a chemical analysis of the soil will show what fertilizer should prove useful. This may be true in a few unusual cases of very poor soil. However, most of our soils contain enough available plant food so that a chemical analysis made by any of the present known methods is no certain guide to the profitable use of fertilizers. It is true that a chemical analysis can show the amounts of the various elements in a soil. But this does not enable the chemist to tell what proportion of any one or all of the essential elements shown by the analysis is in a condition to be useful to plants. For example, a large proportion of the phosphorus and the potassium present in most soils is unavailable to plants. Although this has long

been known, soil chemists have not yet found a satisfactory way to measure that portion of the total of these elements which plants can easily take from the soil.

Further, it may be stated that the cost of an adequate chemical examination of a soil and the difficulty of interpreting the results are so great that such examinations are not made by the University except for research purposes.[4]

No *soil* needs a fertilizer, but all *plants* need the elements supplied by a fertile soil. If the soil is lacking in any one of them, the lack may be supplied by a fertilizer. All plants need the same kinds of plant food, but vary in the relative amounts of the different elements which they need. Also different kinds of plants vary greatly in their ability to absorb enough nutrients for their needs from soils poorly supplied with available nutrients. The needs of any single individual plant vary greatly during the different stages of its life period. Nearly all soils contain all of the elements needed by plants, but differ greatly in the rate at which they are able to supply these elements to growing plants. If the soil supplies nutrients too slowly the growth of plants will be slow.

Some scientists have sought to estimate the so-called 'need' of a soil for fertilizers, by analyzing the plants grown on the soil in question.[5] The results have often been disappointing because plants take up more or less of the fertilizer elements somewhat in proportion to the easily available supply in the soil. When the supply is large, plants may absorb very much more nitrogen, phosporus, and potassium than they need for normal growth. Such excessive absorption of nutrients is known as 'luxury' consumption. Probably it may be considered as largely a waste of plant food. The important point here is that plants may, with little abvantage to themselves or to their grower, absorb from highly fertile soils uselessly large amounts of fertilizer elements. If crops make a good normal growth without fertilizers, it is doubtful whether it will pay to apply them.

Only actual trials with the particular kind of plant in question can show what is the best fertilizer in any given case.

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[4] For a more extended discussion of this subject see: Hoagland, D. R. Fertilizer problems and analysis of soils in California. California Agr. Exp. Sta. Cir. **317**:1–16. 1930.

[5] This does not refer to the Neubauer method now much used in Germany.

HOW MAY THE NEED OF FERTILIZERS BE KNOWN?

An experienced observer may sometimes be able to detect the lack of certain plant nutrients in a soil by the appearance of vegetation growing on that soil. Some of the indications of need of fertilizers will be mentioned in this connection. Positive proof that fertilizers will pay in any particular case is usually to be had only by actual trial. More than one trial may be necessary.

Lack of available nitrogen is indicated by slow growth, yellowish instead of dark green leaves, early dropping of leaves of trees, stunted plants, early going to seed, unfruitfulness. However, some of these appearances may be caused by lack of moisture or other unfavorable conditions.

Lack of available phosphate is difficult to recognize. It may cause slow development of cereals, late fruiting, low yields, unthrifty appearance.

Lack of available potash is sometimes indicated by unhealthy plants, susceptibility to disease, brown patches on margins of leaves, and premature dying of leaves from the edge toward the midrib. Too much alkali or salts may have somewhat similar effects.

EXPERIMENTING WITH FERTILIZERS

Since soil analysis is, in general, not able to show definitely whether or not a fertilizer will increase profits from a piece of land, the only satisfactory method is to try a fertilizer. Every farmer should be an experimenter to some extent. It is not necessary to make the experimenting very costly or elaborate. A small plot will usually show pretty well the effects of any kind of application, provided such effects are large enough. If the fertilizer application produces no benefit, not much is lost. But if the experiment indicates that the material in question will be helpful or profitable, next year the whole field may be treated, without much risk of great financial loss, although the benefits to be derived from the use of fertilizers may vary greatly with the time of the year and with different years on the same ground. It is very difficult to ascertain the most useful fertilizers for fruit trees, so that the above statements will be only partially, or not at all true of them.

One who desires to try some experiments may well seek the advice of the county farm advisor, or any other person qualified to give

expert advice on the subject. The farm advisor may obtain additional help, if necessary, from the Experiment Station.

In order to secure reliable results in the use of fertilizers, it is necessary to take into consideration a number of different factors, such as the character of the soil, both physical and chemical, the climate, the kind of crop to be produced, the proximity of a profitable market for the crop, and the commercial value, or acre value, of a crop. It is not possible to make a satisfactory recommendation of fertilizer for any particular crop, without knowing something at least of all these factors. The physical character of the soil will make a great deal of difference in the way both crops and fertilizers act. The chemical character of the soil determines to a large extent what fertilizers will give the most desirable results. But, as already stated, chemical analysis may frequently be unable to show definitely the capacity of a soil to supply nutrients to a growing crop. Knowledge of the subject of fertilization is not at present complete enough so that it is possible to state with any certainty what will be the effect of the addition of fertilizers on most soils, and upon most crops. In extreme cases of lack of any particular fertilizing substance, or of presence of an unusual amount of any one chief fertilizing substance, it is usually possible to state definitely what will be the effect of addition of a fertilizer, but most soils are in the class between these two extremes, so that the results cannot be definitely foreseen.

The main purpose of an experiment is to obtain information. The fullest and most useful information is had only by careful planning of the experiment.

In planning an experiment with fertilizers, a number of points are to be considered:

1. Have a number of check (untreated) plots between the treated plots, so that results on untreated ground may be compared with those on fertilized ground. Have 'guard' rows or plots between treated plots and the check rows or plots so that there will be no chance for the check plots to be influenced by the material applied to the fertilized plots.

2. Repeat each treatment on several plots.

3. Try it for more than one year. A single season's trial may give very misleading results, especially with trees.

4. Select a soil as uniformly alike all over as possible on which to lay out the experiment plots.

5. Make the plots as nearly uniform as possible in size (1/20 acre is a good size), slope, and other conditions. Run the plots up and down the slope, if there is a slope, not across it.

6. Select the fertilizers most likely to produce the desired effect.

7. Try large and small amounts of the fertilizers.

8. Mark the plots and mark the treatments.

9. Make a map showing location and treatments of plots.

10. Keep a written record of all the plots and all the treatments showing location, nature and amount of treatment, and results obtained.

11. Measure and weigh both treatments and crops and record carefully so that actual figures show the results. It is not safe to draw conclusions from appearance only, in most cases.

DISAPPEARANCE OF PLANT NUTRIENTS FROM THE SOIL

Most farmers are aware that the fertility of the soil decreases with use. Many may be interested to know something of how this happens.

Great quantities of plant nutrients are removed from the soil by crops. If these crops are sold and removed from the land, the soil becomes gradually poorer. The bad effects of this process are to be seen in many places. In New England and the south eastern states they appeared long ago, later in the central states, now they are seen in Kansas and Nebraska, and in a few long-cultivated parts of California. When most of the crops are fed to animals, the manure being returned to the soil and only meat or milk sold, the fertility of the soil may be retained for a long time.

Where there is much run-off from the land due to rainfall the water carries away some of the richest top soil, and at the same time some nitrogen is lost in the drainage. Such losses by erosion from fertile soils are enormous in some parts of the United States, and most of them are not difficult to prevent. Very little phosphorus or potassium are lost in the drainage, as these elements are held very tenaciously by good soils. After these elements have once been thoroughly incorporated in the moist soil it is very difficult to wash them out by water. Most of the nitrogen used by plants is absorbed from the soil in the form of nitrates. These are easily soluble in water and easily washed out by water. To avoid this sort of loss during time of heavy rains, a green crop, called a covercrop, is sometimes grown on the soil. This active growth absorbs much of the easily available nitrate nitrogen, converts it into plant substance, and prevents loss. Later when the covercrop is plowed under, the nitrogen is again gradually converted into the nitrate form and thus

made available to the next crop. Combined nitrogen in plant material is not easily carried away in the drainage.

Besides loss of nitrogen in crops and in the drainage, there is sometimes considerable loss from waterlogged soil caused by undesirable bacterial action. This may usually be avoided by providing good drainage so that water does not stand long on the land and so that the soil may always contain considerable air. Under some conditions of cultivation, yet imperfectly understood, even when the drainage is good, large losses of nitrogen from the soil to the air may take place, as a result of the activities of certain types of microorganisms. Such losses sometimes may be much greater than the amount of nitrogen removed by crops.

Although phosphorus and potassium are not lost from the soil in the same way that nitrogen is, they frequently enter a condition and location in the soil in which they may be of little use to plants. This is due to what is known as fixation.

FIXATION

When potassium, phosphate, or ammonium salts are added to a soil which contains much clay, from 50 to 99 per cent of the potassium, phosphorus, or nitrogen becomes fixed by the clay almost instantly. The important fertilizing element combines with the clay so that it is not easily washed out by water. This fixation takes place in the top few inches of the soil, that is, in that portion of the soil with which the fertilizer is mixed. In a semiarid climate the feeding roots of trees, alfalfa, and many other plants are frequently far below the surface of the soil. So it is probable that such plants feel little immediate effect of phosphate or potassium fertilizers as usually applied. During the course of many years it is likely that some of the phosphate and potassium will be carried gradually deeper into the soil to a region where they can be absorbed by the roots. Ammonium salts are different, because they are usually converted to nitrates in a few weeks. In this condition the nitrogen is not fixed, but is easily moved through the soil by water.

The farmer does not want to wait several years for the fertilizer to become accessible to the roots of his plants; he wants immediate results. To this end three methods may be somewhat effective. First, apply the fertilizer in such a way that it will at once be placed deeply in the soil where absorbing roots are most numerous. To do this without injuring the roots special apparatus, not readily available, may be necessary. Second, apply much larger than the usual amounts

of fertilizer. In this way some of it is likely to be carried deeper into the soil before becoming fixed, so that plant roots may have contact with it. When ordinary amounts are not effective, it is suggested that heavy applications be tried on a small portion of the field before concluding that fertilizers will do no good. But, too much may act as an alkali, and injure the plants. A third method would be to adopt farming practices which will encourage surface rooting.

Frequently no useful effect is observed following applications of small amounts of fertilizer. Often there is no lack of available plant nutrients. But, in many cases, if the soil is lacking in available nutrients, it is possible that the failure of the fertilizer is caused by fixation. The fertilizer elements may remain so near the top of the ground that absorbing roots do not come in contact with them.

Even though the soil may have high fixing power, it is possible for plants to make satisfactory absorption of nutrients from near the top of the ground if important root development takes places near the surface of the soil. Moisture conditions favorable to surface development of roots may have an important modifying influence. It is fairly well established that, in most soils, plant roots are able to absorb a large part of the fertilizer even though it is fixed by the soil, provided the roots can come into contact with the soil containing the fixed fertilizer. However, in some soils, added phosphate may slowly become entirely unavailable to plants. Some investigators believe that the same may be true of potassium.

CARRYOVER

On account of fixation of phosphate, and of potassium, and of the incomplete use of nitrogen compounds added to the soil in organic combinations, a considerable part of the plant nutrients applied to the soil as fertilizers in any one year may remain unused until the next year or longer. In England this 'carryover,' as it is called, is usually allowed for in the renting of land. Experience has enabled farmers to make a reasonably just estimate of the value of the 'carryover.' A record is kept of the amount and kind of fertilizer applied each year. When a new tenant rents the land he expects to pay for the estimated value of the 'carryover' of fertilizer just the same as though it were in the more tangible form of live stock or implements.

Experience seems to be the only important available means of estimating the value of fertilizers thus carried over from one year to the next. Some substances, such as farm manures, may have a 'carryover' value for several years, not just one season.

AVAILABILITY OF FERTILIZERS

The term availability in respect to fertilizers has two quite different meanings. In relation to plants, available substances are those which plants can readily absorb and utilize. This might be called the agricultural availability of the material. In reference to fertilizers the word available refers to that portion of the total nutritive substance in a fertilizer which is found to be available according to some laboratory method. This is the commercial availability of the fertilizer. These laboratory methods are designed to show how much of the plant food in any material is ready for immediate absorption by a plant. Although the figure for availability found by any laboratory method is quite abritrary and only roughly indicates how much of a fertilizer may be easily assimilated by plants, it is usually a useful means of comparing different fertilizers to show their relative values. Chemists have spent much time and effort in trying to devise satisfactory methods for determining availability. The results are only partially satisfactory, yet must be accepted until better are found.

Any fertilizer which is easily soluble in water is considered wholly available; such fertilizers are nitrates, the ordinary potassium salts, and water-soluble phosphates. Exceptions are ammonium sulfate and urea, which though easily soluble, must have their nitrogen converted to nitrates before they become immediately available to most plants. Nitrification of these materials is usually easy, rapid, and complete, so that they are highly available. Tankage, fish-meal, and bone-meal, gradually become available and are considered high-grade fertilizers, although at the present time they are too expensive for general use. Garbage tankage, leather meal, wool waste, etc., become available so slowly that they are considered as low-grade fertilizers. The availability of these low-grade materials may be much improved by chemical treatment. Rock phosphate is only slowly available to plants, but by treatment with sulfuric acid the highly available superphosphate is produced.

Although most of the low-grade materials are of little immediate value as fertilizers, they may supply possible plant nutrients at low cost. If the soil contains enough lime and organic matter to make a favorable environment, the low-grade fertilizers gradually become available and may supply plant food more cheaply than the high-grade materials.

The user of fertilizer should consider carefully the availability of any materials he intends to buy. If he wants immediate results, the fertilizer should be nearly all quickly available.

THE EFFECT OF FERTILIZER RESIDUES ON SOIL AND CROPS

Most fertilizer materials are, chemically speaking, salts. A salt consists of two very different parts, an acid and a base. In some cases both the acid and the base may supply plant nutrients. But a number of salts used as fertilizers leave in the soil a residue of acid or base not absorbed by plants. This residue is of little or no use to plants and may be injurious to the soil. Before buying a fertilizer, the farmer should know what residue it may leave and the effect of that residue on soil and crop.

Sodium nitrate leaves a residue of sodium, which becomes either sodium carbonate or sodium bicarbonate (black alkali) in the soil, unless the soil contains some acid to neutralize them. Ammonium sulfate leaves a residue of sulfuric acid which tends to make the soil acid. Conditions may arise in which such residues are injurious to crop growth, but in California very few cases of this kind have been reported. If these two sources of nitrogen are used together or alternately, the residue left is sodium sulfate, a relatively less injurious substance. Potassium chloride, often called muriate of potash, leaves a residue of chlorine which is generally not of important magnitude in comparison with the chlorine already present in the soil or irrigation water. However, in special cases the use of chloride may be open to question. This fertilizer has been used in some places for many years without apparent injury to the soil, especially if used along with organic matter.

Acid residues are left in the soil by ammonium sulfate, acidulated tankage or fish, leunasalpeter, and some others. Basic or alkaline residues are left by sodium nitrate, calcium nitrate, basic slag, rock phosphate, and bone-meal. Since the basic residue of all of these except sodium nitrate is lime, their residues are generally harmless, sometimes beneficial, tending to correct soil acidity. On certain soils, no bad effects have been noted from ammonium sulfate or sodium nitrate, even when these forms of nitrogen have been used for many years. Each soil condition must be given individual consideration. The same fertilizer may have somewhat different effects on different soils, and even on the same soil at different times or seasons.

WHY FERTILIZERS SHOULD BE USED

Soil fertility, or crop-producing capacity, is diminished by the usual systems of farming. But labor and other expenses of producing crops may be nearly the same for a poor crop as for a good one. The bigger and better the crop that can be grown on the land, the greater should be the profit. If fertilizers are found to increase crop yields, the increase will cost little more than the price of the fertilizer and additional cost of application and harvesting. It may pay to use fertilizers in amounts up to the point where increased profits cease to be much more than the increased cost. The greatest profits are made by those who secure the greatest average yields of good quality products. But extremely high yields produced by means of applications of excessive amounts of fertilizers may not be profitable because of the great cost of the fertilizer. On the other hand, farming which produces much less than average yields is not likely to be profitable. If the soil has become so poor through continuous cropping that farming it no longer pays, it is possible that it will pay to use fertilizers. However, some soils are naturally so poor and others become so exhausted by cropping or abuse, that it is not commercially feasible to bring them to good productiveness because of the enormous amounts of fertilizer that would be required.

To profit by the use of fertilizer, it is necessary to know what and how much to use. If this cannot be learned from the experience of neighbors, or from the farm advisor, it must be found out by field tests with the aid of such scientific knowledge as is available and applicable. If crop yields are decreasing year after year, the cause may be one or more of several conditions, such as: lack of moisture, accumulation of alkali, loss or scarcity of organic matter, bad physical condition, effect of plant diseases or pests, presence of toxic substances developed by continuous growing of one kind of crop, or lack of available plant nutrients. If the last is the cause of poor crops, fertilizers may be the means of securing better yields. If they are already being used, it may be that the quantity is too small, or that the right material is not being used. When a fertilizer is used as an experiment a liberal amount of it should be applied so that there will be no doubt as to its effect.

HOW TO SELECT A SUITABLE FERTILIZER

It is not possible with present knowledge to give directions insuring certain success in a choice of fertilizer for any particular crop. Some suggestions may be helpful.

Soil, climate, season, water supply, the particular crop desired, the market for the crop, the time when the fertilizer is to be applied, and other variables should be considered in selecting a fertilizer. Since some of these are not well known in advance and some cannot be controlled, choice of the most effective or best fertilizer for any purpose is partly a matter of chance and partly of experience. Books have been published and experiment stations have issued bulletins making definite recommendations of fertilizer mixtures for certain crops in some definite place. Such advice, if based on experience, may be fairly reliable for the localities concerned. However, in most parts of California neither scientific knowledge nor practical experience is sufficient to warrant such explicit statements.

The problem consists of two parts, what mixture to use and how much of it to apply. Of course all three, nitrogen, phosphorus, and potassium must be in sufficient supply to make good, normal, healthy plants, but an excess of one or the other may favor the particular kind of growth most wanted. If plants are yellow and grow slowly, nitrogen may be deficient, sometimes iron. If potatoes are soft and watery, potassium and perhaps phosphorus may be needed. In some cases failure of satisfactory growth is not from lack of any of the three main fertilizer elements but from too much of some harmful substance such as manganese, boron, or excessive salts (alkali soil). Too little or too much moisture in the soil is a common cause of poor crops in California. It seems unlikely that ordinary soils lack sufficient copper, zinc, boron, manganese, and other elements needed in very small amounts to promote healthy normal growth of plants. Sometimes poor growth is due to excessive lime in the soil so that iron and phosphate are made unavailable.

In selecting fertilizer mixtures it seems best, unless the soil is already well supplied with them, to include sufficient amounts of potassium and phosphate to balance the nitrogen, since the latter is the expensive part of the mixture and also the part most liable to loss or waste. If some excess of phosphate and potassium, not needed by the crop, is left in the soil it will not be lost, but if sufficient amounts of them are not already present in the soil to permit most

effective use of the nitrogen, some of this expensive element will be wasted. Experiments in numerous places in California have shown that nitrogen is the element most likely to more than pay for its cost when used as a fertilizer. Of course, if it is known that the soil is well supplied with any of the three, there is little gain to be expected from adding more of the same element. For example, peat soil usually contains plenty of available nitrogen. Experience indicates that usually addition of nitrogen fertilizers to peat in the San Joaquin delta has little or no beneficial effect on crop production. On the other hand, it frequently happens in California that no effect is produced by any other element of the fertilizer than nitrogen. When a fertilizer mixture produces a profitable increase in crop yields, the question should be asked whether the nitrogen alone is responsible. For special crops of high acre value, the cost of fertilizer may sometimes become a minor consideration if by the use of large amounts it is possible to secure great profit through larger yields, better quality, or earlier marketability of the crop. In other words, the quantity of fertilizer which can be used advantageously depends on the cost of the fertilizer and the value of the crop.

FERTILIZERS FOR SPECIAL PURPOSES

The following notes in regard to fertilizers for certain soils, crops, seasons, etc., are offered merely as suggestions as to what is likely to prove most useful or effective. They are not intended as recommendations or directions to be followed without question. Every case where a fertilizer is to be used should be considered as an individual case to be treated according to its own needs and conditions.

Sandy soils are liable to be deficient in nitrogen. In humid climates they easily lose fertilizers, and hence frequent light applications of a complete fertilizer not high in nitrogen are suggested. But in California, especially in the drier portions, sandy soils frequently have adequate supplies of phosphate and potash. In this case, only nitrogen fertilizers may be needed. Sometimes organic matter alone may be sufficient.

Clay soils are usually richer than sands and do not so easily lose plant nutrients. Which of the three, nitrogen, phosphorus, or potassium will be most useful depends upon local and crop conditions. Some of our red hill soils of volcanic origin and some of the poor drab valley loams respond markedly to phosphate for some crops. Peat and muck soils are usually well supplied with nitrogen, but decidedly lacking in available phosphorus and potassium.

Acid soils having little organic matter are often poor in all plant nutrients. For some crops they should be given a complete fertilizer, perhaps lime also, and effort should be made to increase the content of organic matter.

Alkali soils usually contain a good supply of plant nutrients, but the presence of excessive amounts of salts makes them infertile. When the soil is flooded to wash out the undesirable salts there is likely to be a large loss of plant nutrients along with the alkali. Nitrate in particularly is liable to be lost. After the washing out process is completed it may be very helpful in starting a crop on the leached soil to add some nitrate and perhaps a moderate amount of a complete fertilizer.

In regard to crops, the legumes in general, such as beans, peas, alfalfa, clover, melilotus, etc., are not so likely to need nitrogen on account of their nitrogen fixing power, but often respond well to phosphate. Most legumes do better in soils well supplied with lime and some of them will hardly grow in very acid soils. It seems that this is partly because the nitrogen-fixing bacteria do not thrive in acid soils. Failure of legumes on some slightly acid soils is sometimes caused by lack of available phosphate.

In order to start almost any crop (even the nitrogen-gathering legumes such as alfalfa) on sandy, poor, or exhausted soil, a moderate amount of readily available nitrogen, in the form of a nitrate, is likely to be very helpful; manure is especially good. This enables the plants to make a quick start at a time when nitrification is slow. Later when the plants have become established they will be much better able to supply their needs from the unproductive soil.

Fodder crops, such as grain hay, sudan grass, millet, etc., may be greatly increased by ample nitrogen, when moisture and other conditions are favorable. But too much nitrogen, especially if phosphate or potassium is deficient, induces a rank soft growth unusually subject to plant diseases. Such rank growth may exhaust the soil moisture too early. Heavy rain or wind is liable to cause such plants to lodge badly.

Grass lawns are greatly stimulated by nitrogen, especially by nitrate in a cold, wet spring when nitrification is still slow. After the ground becomes warmer and drier, ammonium sulfate is one of the best lawn fertilizers. If all the grass clippings are removed from the lawn, much phosphate and potash will be carried away so that occasionally a complete fertilizer containing nitrogen, phosphorus, and potassium should be spread on the lawn. This is preferable to ordinary manure, which may bring in weed seeds.

Vegetable gardens need liberal amounts of available plant nutrients to produce healthy, rapid succulent growth. Flower gardens may be treated in the same way. But there is great variation among flowers in response to fertilizers. Great success with flowers is most likely to be obtained only by an understanding study of the fertilizer needs of the individual species.

METHODS OF APPLYING FERTILIZERS TO THE SOIL

Fertilizers are distributed by hand, by spreading with a shovel, or by a machine similar to a seeder or a grain drill. The latter is usually best. Sometimes the material may be broadcasted, then harrowed in where it is to be applied in the rows of plants. The best plan is to have a fertilizer distributor attached to the seeder in such a manner that the fertilizer is placed in the ground in front of and a little lower than where the seed is dropped., Thus it is covered with a little soil before the seed is dropped so that the seed is a little above and out of contact with the fertilizer. The fertilizer should be dropped an inch or more below the seed. Most fertilizers are likely to injure the seed if allowed to come in direct contact with it. Mehring and Cumings have written a good monograph on the subject of fertilizer distributors.[6]

Jensen says,[7] "A good fertilizer should have the following named properties:

1. Place the fertilizer in the best location relative to the seed;
2. Have uniform rate of delivery;
3. Be easily adjustable for different rates of delivery;
4. Be capable of a wide range of rates of delivery;
5. Have a hopper large enough so that refilling will not have to be inconveniently frequent;
6. Have visible feed so that the operator may easily see that it is working properly;
7. Have an effective agitator in the hopper so that the material will be continuously delivered;
8. Be easily emptied and cleaned, in order to avoid corrosion of the metal parts by the fertilizer."

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[6] Mehring, A. L., and G. T. Cumings. Factors affecting the mechanical application of fertilizers. U. S. Dept Agr. Technical Bul. 182:1–96. 1930.

[7] Jensen, O. F. Methods and equipment for applying fertilizer. Amer. Fert. 72:15–21. 1930.

In applying fertilizers to fruit trees or other permanent plants, the great difficulty is to get them down into the soil where they will be accessible to the feeding roots. Ordinary applications of phosphate or potash on top of the soil are likely to be fixed so near the surface that the trees are little benefited. At present, there seems to be no machine available which can place the fertilizer deep enough for immediate effect on fruit trees. A methods which has been used by Michigan State College consists in boring numerous holes in the soil about the tree with an electric drill. The holes are made deep enough so that the fertilizer can be placed close to the active roots of the tree.

If the fertilizer material is to be used on a small garden area, and if it is soluble in water, the best plan is to dissolve it in water and sprinkle the solution on the soil or over the plants or a lawn. Immediately after this the whole should be well sprayed with water to wash the fertilizer off the plants and carry it into the soil.

WHEN TO APPLY FERTILIZERS

When to apply a fertilizer depends upon the kind of fertilizer and the crop. So far as the soil is concerned there is perhaps little difference except that nitrates or materials which will soon generate nitrates should not be applied just before heavy rains are likely to occur which might wash away the nitrate into the drainage underground. Nitrate is apt to be most helpful to young plants in early spring when the cold, wet soil usually contains very little nitrate after leaching caused by heavy winter rains. Under such conditions the readily available nitrate enables the young plants or a grass lawn to make vigorous early growth before the normal rapid nitrification of the warm summer supplies plenty of nitrate. Organic nitrogen compounds should be applied to the soil from two to ten weeks before the time it is desired to have the nitrogen converted to nitrate ready for the plant to absorb.

With respect to the crop, the time when there is plenty of nitrate available may materially modify the character of the crop and the time it will mature. Much nitrate in the soil near the time of ripening may delay maturity. If an early crop is wanted, nitrate should be scarce during the later portion of the growth period, and some investigators think available phosphate should be plentiful at this time. This is likely to be the ordinary condition in nature. Most of the nitrate is used up in the earlier part of the season, but the growth of the plant is most active toward the end of its growing period when

most of the nitrate has been used up. At this time the plant roots are setting free in the soil large amounts of carbon dioxide, which tends to make phosphate more soluble thus, according to some writers, promoting ripening. Besides prolonging the growth period, nitrate may considerably modify the quality of the product, so that according to the quality of fruit or grain desired the nitrate should be made available at the proper time to produce the effect wanted.

So far as the soil is concerned, time of application of phosphate and potassium may be relatively unimportant, but for plants it is best to have a sufficient supply in the soil, ready when it is needed. Many kinds of plants can advantageously use much of these elements during the early stages of their life. If the supply is ample when they are young, little may be needed later. Other plants need a continuous supply of all nutrients. Here it is impossible to make specific recommendations for different kinds of plants.

HOW MUCH FERTILIZER TO USE

How much fertilizer it will pay to use must be determined largely by experience. A high-value crop may warrant use of large amounts, while it may not pay to use any on a low-value crop. Usually a small amount of fertilizer causes a much greater increase of crop on a poor soil than on a good soil. Also the gain from the use of each additional amount of fertilizer becomes less and less as more and more of the material is used. It may pay to keep on increasing the amount used as long as the increase in crop more than pays for the fertilizer used. But if good crops are possible without use of fertilizers it is questionable whether it will pay to apply them. Amounts actually used in practice vary from a few hundred pounds to more than a ton per acre. Smaller amounts may give no perceptible effect. From one to ten pounds of nitrogen or potassium fertilizers may be given to a single fruit tree, depending on its kind, its size, and on the character of the soil. Rarely much larger amounts of fertilizers may be applied. The amount of fertilizer to be applied to an annual crop may vary greatly, according to the probable price of the crop in different years. On the other hand, some soils are so poor that it does not pay to try to make them productive by the use of fertilizers in any amount whatever.

In estimating how much fertilizer to use to the acre, only the actual plant food in the material should be counted, that is, pounds of nitrogen, phosphorus, and potassium. The farmer should estimate how

many pounds of each of these elements he can use advantageously and calculate how many pounds of the proposed fertilizer will be required to supply the needed plant food, then use that amount. To apply a hundred or a thousand pounds of some mixed fertilizer without regard to its composition is very poor business. Whatever result may follow, it is impossible to know what was the cause, unless the composition and amount of fertilizer applied are known. Table 1 may aid in calculating how much fertilizer to use on areas smaller than an acre, such as lawns or gardens.

TABLE 1

POUNDS OF FERTILIZER FOR VARIOUS AREAS IN ORDER TO GIVE A CERTAIN RATE PER ACRE

Rate per acre	Corresponding amounts of fertilizer for smaller areas		
	1,000 square feet	100 square feet	1 square yard
pounds	*pounds*	*pounds*	*ounces*
100	2 50	0.25	0 4
200	5.00	0 50	0 8
300	7.50	0.75	1 2
500	12.50	1 25	2 0
800	20.00	2 00	3.2
1,000	25.00	2.50	4.0
2,000	50.00	5.00	8.0

THE FERTILIZER CONTROL

In most states where much fertilizer is used, the sale of fertilizer is supervised by the state so that manufacturers and dealers will operate honestly and the consumer may buy intelligently. In California this supervision is one of the duties of the Division of Chemistry of the State Department of Agriculture. According to the Fertilizer Control Act, all sellers of fertilizers having a value of 8 dollars or over a ton must procure a license from the division of Chemistry, and register with that office the brand names and guaranted composition of all fertilizers they wish to sell in this state.

Every package of fertilizer offered for sale in California is required by law to have a plainly marked tag or label showing:

1. Name and address of manufacturer or dealer
2. Brand name of the fertilizer
3. Number of pounds in the package
4. Minimum per cent of nitrogen, phosphoric acid, and potash contained in the goods with a statement showing the source or kind of material from which each is derived.

These statements made by manufacturers are usually reliable and constitute the 'guaranteed analysis.'

Official inspectors from the State Department of Agriculture Division of Chemistry go about the state taking samples of fertilizer offered for sale. These samples are analyzed by the chemists of the Division of Chemistry and the results are published in a bulletin which may be obtained by anyone on request to the Division of Chemistry at Sacramento. If the composition of the fertilizer is found materially different from the guaranteed analysis the manufacturer is liable to a fine or loss of his license.

Any consumer of commercial fertilizer in this state may have a sample of the fertilizer he is buying analyzed by the Division of Chemistry on payment of a fee of 2 dollars. In this way the farmer may know exactly what he gets for his money and be protected against unscrupulous dealers. Also commercial chemists in most of the larger cities will analyze fertilizers for anyone.

WHERE TO OBTAIN FERTILIZERS

Small amounts of fertilizer are sold by some grocers, hardware stores, feed stores, and florist shops. Lots of 100 pounds or more are supplied by regular dealers in fertilizers in the principal cities. The report of the State Department of Agriculture Division of Chemistry contains a list of all licensed manufacturers and dealers in the state. The list for 1930 is given below:

REGISTERED FERTILIZER MANUFACTURERS AND DEALERS[8]

The California Fertilizer Act provides that fertilizers can not be legally sold in this state except by those manufacturers and dealers, and their authorized agents, who have obtained certificates of registration from the State Department of Agriculture. No person or company has a right to use any registration number except in connection with the firm name to which the registration certificate of such number has been issued. No person or company to whom a registration number has been assigned has a right to allow any other person or company to use said registration. No agent has a right to use his principal's registration number in connection with his own name.

The following list of registered fertilizer manufacturers and dealers includes all those registered up to December 31, 1930, for the fiscal year ending June 30, 1931:

[8] Elmore, J. W. Commercial fertilizers agricultural minerals (1930). California State Dept. Agr. Special Publication **104**:13–14. 1931.

Advance Fertilizer Works, P. O. Box C, Beverly Hills, Calif.
Agricultural Chemical Works, Inc., 905 Macy St., Los Angeles, Calif.
American Cyanamid Sales Co., Inc., Foothill Blvd., Azusa, Calif.
American Fisheries Co., P. O. Box 796, San Diego, Calif.
American Potash & Chemical Co., Trona, Calif.
American Soda Products Co., Moorestown, New Jersey.
Anaheim Fertilizer Co., Box 231, Anaheim, Calif.
Bakersfield Market, Inc., 1221 19th St., Bakersfield, Calif.
Bandini Fertilizer Co., 4139 Bandini Blvd., Los Angeles, Calif.
Barrett Co., The, 40 Rector St., New York City.
Bay City Shrimp Co., 736 Sacramento St., San Francisco, Calif.
Bayle, Lacoste & Co., 6359 Bay St., Emeryville, Calif.
Big 7 Fertilizer Works, 317 S. New Hampshire Ave., Los Angeles, Calif.
Blake, Albert W. Seed Co., 1055 Lincoln Ave., Pasadena, Calif.
Blumer, A. M., 433 California St., San Francisco, Calif.
Brown, Sewall S. & Co., P. O. Box J, Los Gatos, Calif.
California Fertilizer Works, 444 Pine St., San Francisco, Calif.
California Special Fertilizer Co., 1063 E. Walnut St., Pasadena, Calif.
Central Produce & Fertilizer Co., 106 Weller St., Los Angeles, Calif.
Chapman, I. S. & Co., Inc., 101 S. E St., San Bernardino, Calif.
Cia Ind. Jabonera Del Pacifico, S.C.L., Box 827, Calexico, Calif.
Coast Chemical Co., 1107 E. 12th St., Los Angeles, Calif.
Coast Fishing Co., 621 S. Fries Ave., Wilmington, Calif.
Columbia Steel Co., 1409 Russ Bldg., 235 Montgomery St., San Francisco, Calif.
Copra Oil & Meal Co., Ltd., 617 E. 1st St., Los Angeles, Calif.
Doty, W. H., 243 Lincoln Ave., Pomona, Calif.
Eureka Fertilizer Co., 1116 E. 48th St., Los Angeles, Calif.
Farm Bureau Supply Co., P. O. Box 772, Lindsay, Calif.
Fertilspray Co., The, 2318 W. Washington Blvd., Los Angeles, Calif.
Ford Motor Co., 3674 Schaefer Road, Dearborn, Mich.
Franco-Italian Packing Co., Inc., 231 Fish Harbor Wharf, Terminal Island, Calif.
Fruit Growers Supply Co., Box 530, Station C, Los Angeles, Calif.
Fuhr, Geo. W., 1033 Solando Ave., Azusa, Calif.
G. & M. Products Co., 1244 E. 12th St., Oakland, Calif.
Germain Seed & Plant Co., 747 Terminal St., Los Angeles, Calif.
Globe Grain & Milling Co., 907 E. 3rd St., Los Angeles, Calif.
Great Western Electro-Chemical Co., 9 Main St., San Francisco, Calif.
Gross, E. B. Canning Co., Wave St., Monterey, Calif.
Growers Fertilizer Co., 429 Davis St., San Francisco, Calif.
Halfhill Co., The, 1855 Industrial St., Los Angeles, Calif.
Hauser Packing Co., 2300 E. 9th St., Los Angeles, Calif.
Inland Fertilizer Co., 4144 Bandini Blvd., Los Angeles, Calif.
International Agricultural Corp., 61 Broadway, New York City.
Inukai, K. Co., 153 5th St., San Francisco, Calif.
Italian Food Products Co., Inc., 1687 W. Water St., Long Beach, Calif.
Kellogg, H. Clay, R.F.D. 1, Box 149, Garden Grove, Calif.
Krumm Manufacturing Co., 2 Orange St., Redlands, Calif.
Lagomarsino, F. & Sons, 712 J St., Sacramento, Calif.
Leffingwell Rancho Co., P. O. Box 218, Whittier, Calif.
Lilly, Chas. H. Co., 164 W. Hanford St., Seattle, Wash.
Los Angeles Chemical Co., 1960 Santa Fe Ave., Los Angeles, Calif.
McKesson-Western Wholesale Drug Co., 200 S. Los Angeles St., Los Angeles, Calif.
McNatt, W. E. & Co., 120 E. College St., Covina, Calif.
Mailliard & Schmiedell, 203 California St., San Francisco, Calif.
Meyer, Wilson & Geo. & Co., 601 Federal Reserve Bank Bldg., San Francisco, Calif.
Miyahara Ferto & Chemical Co., 2714 Hyans St., Los Angeles, Calif.
Monarch Fertilizer Co., R.F.D. 2, Box 411, Whittier, Calif.

Monroe, S. H., 5 Cypress Ave., Los Gatos, Calif.
Mountain Copper Co., Ltd., 112 Market St., San Francisco, Calif.
Mutual Orange Distributors, 514 E. 8th St., Los Angeles, Calif.
North American Agricultural Products Co., 923 E. 1st St., Los Angeles, Calif.
Oehl Packing Co., P. O. Box 234, San Bernardino, Calif.
Ogihara, I. S., 613 W. 165th St., Gardena, Calif.
Ontario Fertilizer Works, Inc., P. O. Box 351, Ontario, Calif.
Ord, R. C., 126 Santa Barbara St., Santa Barbara, Calif.
Pacific Bone Coal & Fertilizing Co., 1100 Financial Center Bldg., San Francisco, Calif.
Pacific Cottonseed Products Corp., 2301 E. 52nd St., Los Angeles, Calif.
Pacific Guano & Fertilizer Co., Station "A", Berkeley, Calif.
Pacific Land & Cattle Co., P. O. Box 608, Imperial, Calif.
Pacific Portland Cement Co., 111 Sutter St., San Francisco, Calif.
Pacific Rendering Co., Box 47, Nestor, Calif.
Pacific Trading Co., Inc., 460 Battery St., San Francisco, Calif.
Pinkham & Gaither, P. O. Box 457, Lindsay, Calif.
Plantabbs, Corp., 1214 Court Square Bldg., Baltimore, Md.
Plant Food Co., 4111 Bandini Blvd., Los Angeles, Calif.
Podd, A. J. Agricultural Chemical Co., 644 E. 87th St., Los Angeles, Calif.
Producers Cotton Oil Co., P. O. Box 1344, Fresno, Calif.
Redlands Oil Co., 3rd and Citrus Aves., Redlands, Calif.
Rynveld, F. & Sons, 925 Howard St., San Francisco, Calif.
Sacramento Feed & Fertilizer Co., P. O. Box 1143, Sacramento, Calif.
San Diego Hiryo Co., care Y. Fujii, Bonita, Calif.
San Francisco Milling Co., Ltd., 500 Berry St., San Francisco, Calif.
Sea Pride Packing Corp., Ltd., 400 Sansome St., San Francisco, Calif.
Sevin-Vincent Seed Co., 855 Front St., San Francisco, Calif.
Shelton Co., The, 126 Beale St., San Francisco, Calif.
Silverthorn, Fred C. & Sons, 1501 Market St., San Diego, Calif.
Southern California Fertilizer Co., 1126 Merchants Exchange Bldg., Los Angeles, Calif.
Sterling Supply Co., 4071 Bandini Blvd., Los Angeles, Calif.
Stimuplant Laboratories, Inc., Nelson Ave. and Rawson St., Long Island City, N. Y.
Struve, Edward F., 749 William St., Pomona, Calif.
Sun Fertilizer Co., 2654 E. 23rd St., Los Angeles, Calif.
Swift & Co., Vigoro Sales Dept., 916 E. First St., Los Angeles, Calif.
Tennessee Copper & Chemical Corp., Glendale-Milford Rd., Lockland, Ohio.
Thornton, A. F., Box 72, San Gabriel, Calif.
United By-Products Co., 4073 Bandini Blvd., Los Angeles, Calif.
Valley Fertilizer Co., Santa Maria, Calif.
Van Camp, Gilbert C., Agent, Municipal Wharf, San Pedro, Calif.
Ventura Packing Corp., P. O. Box 266, Hueneme, Calif.
Wada, George I, Arlington and 182nd Sts., Moneta, Calif.
Western Meat Co., South San Francisco, Calif.
Western Star Vegetable Fertilizer Co., R.F.D. 2, Box 504, Long Beach, Calif.
Western Sulphur Industries, Inc., 905 Macy St., Los Angeles, Calif.
Western Sun Fertilizer Co., 103 W. College St., Covina, Calif.
Wilbur-Ellis Co., 657 S. Anderson St., Los Angeles, Calif.
Yamada, Z. Co., 1019 San Julian St., Los Angeles, Calif.

HIGH-GRADE VERSUS LOW-GRADE FERTILIZER

Some farmers buy fertilizer by the ton and try to get as many tons as possible for their money. For this reason manufacturers sometimes make up low-grade mixtures selling for a low price. In this practice fillers having no fertilizer value are mixed with the real plant nutrients in order to make the mixture cheaper per ton. Such practice is bad for all concerned. There may be some cases where a filler is desirable or useful to maintain proper mechanical condition or to aid in distribution or preservation of the mixture. But modern practice tries to combine materials in such a way that the desired quality is had without use of unnecessary or worthless fillers. This is to avoid the expense of mixing, bagging, and freight on useless material. In most cases the smaller the amount of useless material in a fertilizer, the greater the amount of actual plant nutrients that can be bought for a dollar. Usually low-analysis fertilizers are the most expensive, so far as immediate fertilizing value is concerned.

In some cases substances inherent in the nature of the material are improperly called fillers. In ordinary superphosphate nearly one-half the weight is gypsum, which is produced in the process of manufacture and is not economically separable from the phosphate which is the chief fertilizer substance in the mixture. The gypsum should not be classed as a filler in this case. Ordinary tankage, which is a high-grade fertilizer, contains considerable inert valueless material, not intentionally added. This also is not classed as a filler.

FERTILIZER BRAND NAMES

Most manufacturers of fertilizers prepare a number of mixtures which are usually sold under brand names. Many of these brand names do not indicate the composition of the mixture but imply that it is designed for some particular crop, soil condition, time of year, or other special purpose. Sometimes these brand mixtures are designed as a result of experience suggesting their value for the special purpose indicated by the name. Frequently, however, these brand names have no significance and serve only to induce the buyer to spend his money for a fanciful name, without relation to the value or suitability of the fertilizer for his particular needs.

Recently it has become a common practice to designate fertilizer mixtures by numbers such as 4–10–6, 0–15–5, 10–10–0. In these the

first number indicates per cent nitrogen, the second number, per cent available phosphoric acid, and the third number, per cent potash in the mixture. This system is easily understood, makes no pretenses and gives desirable information as to composition of the goods. But in addition to this, the sources of the several ingredients should be plainly stated.

A fertilizer containing commercial quantities of all three of these elements, nitrogen, phosphorus, and potassium is known as a complete fertilizer. If it contains only one or two of the three principal elements of a fertilizer it is called incomplete.

VALUATION OF FERTILIZERS BY THE UNIT SYSTEM

The 'unit' is a convenient expression used in calculating the commercial value of fertilizers. A 'unit' is 1 per cent of a ton, which is 20 pounds. The price per unit is found by multiplying the price per pound by 20. In buying and selling according to units of fertilizing materials, the seller gets full value for the actual fertilizing material he delivers and the buyer pays for nothing he does not get. Fillers are not paid for. In dealing by this method, a price per unit is agreed to by both buyer and seller. Then a sample is analyzed. The per cent of N multiplied by the price per unit gives the value of the nitrogen in a ton of the fertilizer. In the same way the value of the phosphorus and potassium is found. The sum of the three values is the value per ton. Table 2 gives an example of this method of calculating the cost of a fertilizer.

TABLE 2

EXAMPLE OF A VALUATION OF A FERTILIZER BY THE UNIT SYSTEM

Element	Per cent in fertilizer	Price per pound, cents	Price per unit, (20 lbs.)	Value per ton of fertilizer
Nitrogen (N)	5.00	20	\$4.00	\$4.00 × 5 = \$20.00
Phosphoric acid (P_2O_5)	10.00	5	1.00	1.00 × 10 = 10.00
Potash (K_2O)	4.00	6	1.20	1.20 × 4 = 4.80
Total				\$34.80

HOME MIXING OF FERTILIZERS

Home mixing of fertilizers is not favored by fertilizer manufacturers, since part of their profit is derived from mixing, bagging, and other operations which they are specially prepared for, and which they can do more cheaply and better than the farmer. The chief advantage of home-mixed fertilizers is a reduction in selling costs

which are high for mixed fertilizers. The farmer who uses large amounts of fertilizer and has some storage space and suitable floors for mixing may save considerable in costs of fertilizers by purchasing the materials separately—that is, the so-called 'simples'—and mixing them at home during slack periods when the labor force would not otherwise be profitably employed. Only materials which do not need grinding can be successfully handled in this manner. If only one simple material is to be used or if each fertilizer material is to be applied separately, no mixing is necessary. For the farmer who uses only a few tons a year, home mixing probably would not pay.

The National Fertilizer Association claims that about one farmer in three who use fertilizer has at some time tried home mixing, and that only one of those three who have tried it continues the practice. The reason assigned is that it does not pay, or it is too much trouble, or that the farmer cannot do it well enough.

PRICES OF FERTILIZERS

The prices of fertilizer materials quoted in table 3 are only approximate, at best. They represent the approximate retail cost of the materials in ton lots at shipping points on the San Francisco Bay in July, 1929. The prices of some of these materials are subject to as much as a 20 per cent change over a few months' time. These quotations are given in order to permit the prospective buyer to make a rough estimate of the commercial value of different materials. Before buying a considerable quantity of fertilizer, one should obtain price quotations from more than one dealer in these materials.

Some of these substances have such undesirable physical qualities that they are disagreeable or difficult to handle and apply to the field. The inexperienced person should always obtain the advice or assistance of one who knows them well before buying or attempting to use any of these fertilizers with which he is not well aquainted. The prices of dried blood, tankage, fish tankage, cottonseed meal, and raw-bone meal are relatively high because these materials are much used as feeding stuffs, for which purpose they are more valuable than for fertilizers.

Bird guano and bat guano, formerly common, are now very scarce. Basic slag is common as a fertilizer in parts of Europe, but not at present in the United States, particularly in the Far West. Tobacco stems and some of the low-grade potash salts frequently used in eastern United States are rarely used on the Pacific Coast.

No prices are given for several materials which are not at present available in commercial quantities in this locality.

TABLE 3

APPROXIMATE CONTENT, COST PER UNIT, AND AVAILABILITY OF PLANT FOOD IN COMMERCIAL FERTILIZERS*

Name of material	Composition of material, per cent of			Availability	Cost per unit dollars		
	N	P_2O_5†	K_2O†		N‡	P_2O_5†	K_2O†
Nitrate of soda	15	0	0	High	4 00	....	....
Nitrate of lime	15	0	0	High	3 83	....	....
Leunasalpeter	26	0	0	High	2.98	....	....
Calurea	34	0	0	High	3.29	....	....
Sulfate of ammonia	20 5	0	0	High	3 17	....	....
Cyanamide	20–25	0	0	High	....	....	....
Ammophos	16	20	0	High	3.23	1 44	....
Nitrophoska¶	15	15	20	High	4.00	1.46	1.40
Diammonophos	21	53	0	High	——	....	....
Potassium nitrate	13	0	44	High	....	....	——
Leunaphos	20	20	0	High	——	——	....
Urea	46	0	0	High	....	....	....
Ammonium potassium nitrate	16	0	28	High	....	....	——
Dried blood	12–14	0	0	High	6.78	....	....
Tankage	8	8	0	High	6.50	1.62	....
Fish meal	10	6	0	High	6.50	1.66	....
Bat guano	5–10	5–10	2–10	High	——	——	——
Bird guano	5–10	5–15	0	High	——	——	....
Cottonseed meal	6–9	2–3	1–2	Good	——	——	——
Sheep manure	1.6	0.9	3.0	Good	10.00	2.00	2.70
Chicken manure	2.3	2.8	1.2	Good	5.20	2.00	2.00
Tobacco stems	1–3	0	4–9	Good	....	....	——
Garbage tankage	2–3	1	1	Low	——	——	——
Hoof, hair, leather, feathers, etc.	10–15	0	0	Very low	——	....	....
Peat	2–4	0	0	Very low	——	....	....
Barnyard manure	(0.5–1.5)	(0.4–1.0)	(0.4–1.0)	Medium	——	——	——
Superphosphate	0	18 5	0	High	....	1.41	....
Treble superphosphate	0	48	0	High	....	1.35	....
Phosphate of potash	0	30–50	50–30	High	....	——	——
Basic slag	0	10–25	0	Good	....	——	....
Raw bonemeal	3.7	23	0	Good	6.00	1.10	....
Steamed bonemeal	3	27	0	Good	6.00	1.00	....
Rock phosphate, ground	0	32	0	Very low	....	0.63	....
Potassium sulfate	0	0	50	High	....	....	1.30
Potassium muriate	0	0	62	High	....	....	1.00
Manure salt	0	0	20–30	Good	....	....	——
Kainit	0	0	12–14	Good	....	....	——
Carbonate of potash	0	0	15–50	Good	....	....	——
Wood ashes	0	0	5–10	Medium	....	....	——
Kelp	0	0	3–10	Medium	....	....	——
By-product potash	0	0	10–30	Medium high	....	....	——

* This list of prices is of the time July, 1929, at San Francisco.

New synthetic nitrogen fertilizers containing nitrogen, phosphorus, and potassium in various forms and proportions are now being made so that it should not be expected that this list is complete and up to date.

† In this table the usual commercial designations, P_2O_5 instead of P, and K_2O instead of K, are used in reference to materials supplying respectively phosphorus and potassium.

‡ Cost of nitrogen in ammonium compounds is now (April, 1931) much less than when this table was made up.

¶ This is one of several varieties manufactured by a certain firm.

In calculating the prices per unit in fertilizer containing more than one of the three substances, it has been necessary to assign somewhat arbitrary values to one or two of them, N, P_2O_5, K_2O, and obtain the other by difference, using the price per ton as the basis.

SELECTED READING LIST

Persons desiring further or more extended information on the subject of fertilizers may find what they want in the following list of publications on this and related subjects:

BEAR, F. E.
1929. Fertilizers. John Wiley & Sons, publishers, New York. (Excellent American book on fertilizers.)

CALIFORNIA STATE DEPARTMENT OF AGRICULTURE, DIVISION OF CHEMISTRY.
1920–. Commercial fertilizers. California State Dept. Agr. Special Publications. (Bulletins giving reports and analyses of commercial fertilizers are published from time to time by the California State Department of Agriculture, Division of Chemistry in the Special Publication Series. The most recent one on the subject is Special Publication 104, published in 1931. Copies of these bulletins may be obtained by writing to the California State Department of Agriculture, Sacramento, California. Similar bulletins are issued by other states and may be obtained by referring to the proper office in the respective states.

FRAPS, G. S.
1917. Principles of agricultural chemistry. Chemical Publishing Co., Easton, Pa.

HALL, A. D.
1921. Fertilizers and manures. E. P. Dutton, New York. (Mostly concerned with English conditions.)

LYON, T. LYTTLETON, and H. O. BUCKMAN.
1922. The nature and properties of soils. MacMillan Co., New York. (Chapters 22 and 23 deal with the subject of fertilizers.)

RUSSELL, E. J.
1928. Soil conditions and plant growth. Longmans, Green & Co., New York. (The most thorough and modern treatment available, for English conditions.)

VOORHIES, E. B.
1926. Fertilizers. MacMillan Co., New York.

WHEELER, H. J.
1913. Manures and fertilizers. MacMillan Co., New York. (An extended treatment, but somewhat out of date.)

AGRICULTURAL EXTENSION SERVICE CIRCULARS

No.
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5. Lettuce: Series on California Crops and Prices.
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31. Powdery Mildew of the Grape and Its Control in California.
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33. Rearing Dairy Heifers Free from Tuberculosis and Abortion Disease.
34. Plum Growing in California.
35. Alfalfa Production.
36. Beekeeping for the Beginner in California.
37. Home and Farm Preparation of Pickles.
38. Alfalfa Varieties and Seed Supply.
40. Frost Protection in California Orchards.
41. Prune Culture in California.
42. Peach Culture in California.
43. The California Avocado Industry.
44. Bang's Disease (Infectious Abortion).
45. Zinc Chloride Treatment for Pear Blight Cankers.
46. Cherry Culture in California.
47. Equipment for the Bulk Handling of Grain.
48. The Manufacture of Cottage Cheese.

STATION PUBLICATIONS AVAILABLE FOR FREE DISTRIBUTION

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374. A Survey of Orchard Practices in the Citrus Industry of Southern California.
379. Walnut Culture in California.
386. Pruning Bearing Deciduous Fruit Trees.
388. The Principles and Practice of Sun-Drying Fruit.
389. Berseem or Egyptian Clover.
392. Fruit Juice Concentrates.
393. Crop Sequences at Davis.
394. I. Cereal Hay Production in California. II. Feeding Trials with Cereal Hays.
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423. Apricots (Series on California Crops and Prices).

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425. Apple Growing in California.
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434. Investigations on the Use of Fruits in Ice Cream and Ices.
435. The Problem of Securing Closer Relationship between Agricultural Development and Irrigation Construction.
436. I. The Kadota Fig. II. The Kadota Fig Products.
439. The Digestibility of Certain Fruit By-Products as Determined for Ruminants. Part II. Dried Pineapple Pulp, Dried Lemon Pulp, and Dried Olive Pulp.
440. The Feeding Value of Raisins and Dairy By-Products for Growing and Fattening Swine.
445. Economic Aspects of the Apple Industry.
446. The Asparagus Industry in California.
447. A Method of Determining the Clean Weights of Individual Fleeces of Wool.
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449. Economic Aspects of the Watermelon Industry.
450. Irrigation Investigations with Field Crops at Davis, and at Delhi, California, 1909–1925.
452. Economic Aspects of the Pear Industry.
454. Rice Experiments in Sacramento Valley, 1922–1927.
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456. Yield, Stand and Volume Tables for Red Fir in California.
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485. Drying Cut Fruits.
486. Pullorum Disease (Bacillary White Diarrhea of Chickens).
487. Asparagus (Series on California Crops and Prices).
488. Cherries (Series on California Crops and Prices).
489. Irrigation Water Requirement Studies of Citrus and Avocado Trees in San Diego County, California, 1926 and 1927.
490. Olive Thinning and Other Means of Increasing Size of Olives.
491. Yield, Stand, and Volume Tables for Douglas Fir in California.
492. Berry Thinning of Grapes.
493. Fruit Markets in Eastern Asia.
494. Infectious Bronchitis in Fowls.
495. Milk Cooling on California Dairy Farms.
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498. Pickling Green Olives.
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503. St. Johnswort on Range Lands of California.
504. Economic Problems of California Agriculture. (A Report to the Governor of California.)
505. The Snowy Tree Cricket and Other Insects Injurious to Raspberries.
506. Fruit Spoilage Disease of Figs.
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245. Vine Pruning Systems.
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258. Thinning Deciduous Fruits.
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278. Olive Pickling in Mediterranean Countries.
279. The Preparation and Refining of Olive Oil in Southern Europe.
282. Prevention of Insect Attack on Stored Grain.
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290. The Tangier Pea.
292. Alkali Soils.
294. Propagation of Deciduous Fruits.
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301. Buckeye Poisoning of the Honey Bee.
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